Stormwater toxicity in Chollas Creek and San Diego Bay, California

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ABSTRACT - Stormwater discharges from Chollas Creek, a tributary of San Diego Bay, have been shown to be toxic to aquatic life. The primary objective of this study was to provide the linkage between in-channel measurements and potential impairments in the receiving waters of San Diego Bay. This study addressed this objective within the context of four questions: (1) How much area in San Diego Bay is affected by the discharge plume from Chollas Creek during wet-weather conditions? (2) How much of the wet-weather discharge plume is toxic to marine aquatic life? (3) How toxic is this area within the wet-weather discharge plume? and (4) What are the constituent(s) responsible for the observed toxicity in the wet-weather plume?

The stormwater plume emanating from Chollas Creek was dynamic, covering areas up to 2.25 km^2, based upon measurements of salinity and turbidity. Approximately half of the plume was estimated to be toxic to marine life, based upon the results of purple sea urchin (*Strongylocentrotus purpuratus*) fertilization tests. The area nearest the creek mouth was the most toxic (NOEC = 3 to 12% plume sample), and the toxicity decreased with distance from the creek mouth. The toxicity of plume samples was directly proportional to the magnitude of plume mixing and dilution until, once outside the plume margin, no toxicity was observed. Trace metals, most likely zinc, were responsible for the observed plume toxicity based upon toxicity identification evaluations (TIEs). Zinc was also the constituent identified from in-channel samples of Chollas Creek stormwater using TIEs on the storms sampled in this study, and in storms sampled during the previous storm season.

INTRODUCTION

Stormwater inputs are a large source of pollutants discharged to receiving waters around the country (U.S. EPA 1995a). In southern California, stormwater inputs are among the largest of all sources that discharge pollutants to our coastal water bodies (Schiff *et al.* 2000). Runoff in the southern California region is exacerbated by the area's expansive urbanization, which increases the number of potential non-point sources and promotes runoff due to a larger proportion of impervious surfaces (e.g., cement). The problem is compounded further as a result of the area's infrequent, but intense rainfall events, which promotes the build-up of potentially toxic constituents.

Previous monitoring of urbanized watersheds in San Diego demonstrated that stormwater runoff discharges significant loads of pollutants and was toxic to aquatic life (Schiff and Stevenson 1996, Skinner *et al*. 1998). One such watershed is Chollas Creek, a heavily urbanized (>83% developed) tributary to San Diego Bay. Samples collected near the end of the Chollas Creek channel, approximately 5 km upstream of San Diego Bay, were exposed to both marine and freshwater organisms (Schiff *et al* 2001). Chollas Creek runoff was toxic to both the freshwater and marine organisms; however, the marine organisms were more sensitive (i.e., their response indicated more toxicity). To determine which constituent(s) were responsible for the observed toxicity, toxicity identification evaluations (TIEs) were also conducted on samples of wet-weather discharges from Chollas Creek. Trace metals, most likely zinc, were the constituents responsible for the toxicity to the purple sea urchin. Managers have added Chollas Creek to the state's list of impaired waterbodies, the 303(d) list.

Although in-channel samples of stormwater discharge were shown to be toxic from Chollas Creek, the potential effects that may exist in the marine receiving waters of San Diego Bay remain unknown. This is a common problem nationwide for many stormwater monitoring programs that conduct whole effluent toxicity tests. A link between in-channel measurements and measurements in the receiving water environment needed to be established. The primary objective of this study was to provide the linkage between in-channel measurements and potential impairments in the receiving waters of San Diego Bay. This study attempts to make the linkage by answering four questions: (1) How much area in San Diego Bay is affected by the discharge plume from Chollas Creek during wet-weather conditions? (2) How much of the areal extent of the wet-weather discharge plume is toxic to marine aquatic life? (3) How toxic is the area within the wet-weather discharge plume? (4) What are the constituent(s) responsible for the observed toxicity in the wet-weather plume?

METHODS

General Approach

This project was completed in four integrated stages, each associated with one of the study questions. The discharge plume was mapped based upon physical water quality parameters including salinity, temperature, and turbidity that are tracers of wet-weather discharges. The second stage assessed the extent of the toxicity within the discharge plume by sampling multiple locations along the gradient of plume influence. The purple sea urchin (*Strongylocentrotus purpuratus*) was used as the test species. The magnitude of toxicity was assessed by conducting toxicity tests with dilution series at a site near the most concentrated part of the plume and at the in-channel site upstream of the bay. Toxicity identification evaluations (TIEs) were conducted on samples from the most concentrated portion of the plume and from the in-channel sampling site upstream of the bay during the same storm events to determine the toxic constituents of concern.

Field Sampling

Plume mapping and receiving water sampling occurred during or immediately following rainfall, attempting to capture the maximum extent of the plume. A Sea-Bird Electronics pumped SBE 19 CTD (2 Hz internal recording) was used to make all physical water quality measurements. Sensors on the instrument were temperature, conductivity, pressure (Paine strain gauge, 100 psia), and a SeaTech transmissometer (660 nm, 25 cm pathlength). The pump delivered constantly flowing (18 mL/s) water over the temperature and conductivity sensors, so that slow descent or tow speeds had minimal bias on sensor measurements.

Surface water measurements were made with the CTD hung in the water using a downrigger. The downrigger submerged and stabilized the instrument at an average depth of 0.4 m while the research vessel cruised at slow speeds (< 5 knots). This configuration minimized boat turbulence and plume mixing. A differential global positioning system (dGPS) was connected to the Sea-Bird Electronics data collection system so that latitude and longitude were appended to the CTD data stream. The CTD data were collected at half-second intervals and dGPS positions were updated every two seconds.

Water column profiles were also taken across and along shore of the Chollas Creek mouth. At each water column profile site, surface water samples were taken for toxicity, trace metals, and total suspended solids (TSS). All water samples were immediately placed on Blue Ice in a hard plastic ice chest.

Composited storm samples were collected from within the channel of Chollas Creek at a site upstream of San Diego Bay. These samples were collected using an automated, flow-paced sampler as described in Schiff *et al.* (2001).

Toxicity Testing

All samples of stormwater and receiving water were evaluated for toxicity using the purple sea urchin fertilization test (U.S. EPA 1995b). Details of the test method are given in Schiff *et al.* (2001). In brief, the test consisted of a 20-min exposure of sperm to the samples, eggs were then added and given 20 min for fertilization to occur. Toxic effects are expressed as a reduction in fertilization percentage relative to controls. The purple sea urchins used in the tests were collected from the intertidal zone in northern Santa Monica Bay. The tests were conducted in glass shell vials containing 10 mL of solution at a temperature of 15°C. All stormwater samples were adjusted to a salinity of 34 g/kg with the addition of hypersaline brine prepared by freezing and partially thawing seawater. Three parameters were used to describe the magnitude of toxicity: highest concentration not producing toxicity (no effect concentration, NOEC), concentration producing a 50% response (EC50), and toxic units (TU, 100/EC50).

Toxicity Identification Evaluations

Toxicant Characterization (Phase I TIEs)

A modified Phase I TIE (U.S. EPA 1991, 1996) was conducted simultaneously with baseline testing of stormwater and receiving water samples to minimize holding time and any possible associated change in toxicity. Test conditions were the same as for the baseline test, except that a reduced number of replicates (from five to three) were tested as recommended by U.S. EPA guidance. The salinity of each water sample was adjusted to 34 g/kg before the application of the treatments.

Four treatments were applied to each sample. Ethylenediaminetetraacetic acid (EDTA), a chelator of metals, was added to the test samples at a concentration of 60 mg/L. Sodium thiosulfate (STS), a treatment that reduces oxidants such as chlorine and also decreases the toxicity of some metals, was added to separate portions of each sample at a concentration of 50 mg/L. The EDTA and STS treatments were begun at least 1h prior to the addition of the test organisms to allow interaction with the sample. Samples were centrifuged for 30 min to remove particle-borne contaminants. A portion of the centrifuged sample (200 to 600 mL) was passed through a 1 or 2 g Varian Bond Elut C-18 solid phase extraction column in order to remove non-polar organic compounds. The filtrate was retained for toxicity testing. The C-18 columns were sealed and stored under refrigeration for later elution during Phase II testing. A control sample (laboratory dilution water) was included with each type of treatment to verify that the manipulation itself was not causing toxicity.

Toxicity Identification Evaluations

Toxicant Characterization (Phase 1 TIEs)

The Phase II TIE tests with sea urchin sperm focused upon obtaining information to account for the effectiveness of the EDTA and C-18 treatments during the Phase I studies. These tests had three objectives: (1) to determine whether metal concentrations in the samples were sufficient to cause toxicity, (2) to investigate the effect of C-18 column treatment on trace metal toxicity, and (3) to determine whether non-polar compounds were present in toxic amounts.

The influence of trace metals was assessed by measuring the concentration of dissolved metals in the stormwater and plume samples analyzed for toxicity. Dissolved fractions of trace metals were extracted from the samples with ammonium pyrrolidine dithiocarbamate (APDC) after Bloom and Crecelius (1984). The chelated precipitate was captured on a membrane filter, which was then digested in nitric acid and subsequently analyzed using a high resolution inductively coupled plasma mass spectrometry (ICP/MS) (U.S. EPA 1983). The resulting data were compared to previously established toxicity thresholds for selected metals.

An experiment was conducted to determine whether extraction using a C-18 column altered the amount of toxicity in a sample contaminated with trace metals. Samples of filtered laboratory seawater were spiked with toxic concentrations of either copper (40 μg/L) or zinc (30 μg/L). Each sample was split into two portions, and one portion was passed through a C-18 column using the same procedure applied in previous Phase I TIE experiments. A sea urchin fertilization test was then conducted to compare the toxicity of the C-18 extracted and unaltered samples.

The presence of toxic concentrations of non-polar compounds was investigated by measuring the toxicity of solvent eluates from the Phase I C-18 columns. Each C-18 column was eluted with methanol (MeOH) followed by dichloromethane (DCM) for the February sample or with MeOH only for the March sample. The solvent eluates were exchanged into isopropanol and adjusted in volume so that when a 0.5% solution was made in seawater, a concentration factor of 2 to 3 times the original sample was achieved. Isopropanol was used since MeOH and DCM introduce toxicity to control samples. This maximum concentration and two additional dilutions (50 and 25%) were tested for toxicity using the sea urchin fertilization test.

Confirmation was achieved by first comparing the estimated TUs based upon concentration in each sample to the observed TUs. A second confirmation was achieved by plotting the concentration of the identified toxicants versus reduction in fertilization.

RESULTS

Storm Event Characteristics and Sampling

Plume mapping and toxicity studies were conducted during three storm events that covered a range of rainfall and tidal conditions. The first event occurred on January 25, 2000, and was relatively small; rainfall amounts were less than 0.1 cm. Plume mapping activities required 3.47 hr to complete and occurred across both the ebb and flood cycle of a neap tide; tidal heights increased 0.3 m during surface water measurements. Only two samples were collected for toxicity. The first sample was collected very near the creek mouth and the second was collected in the bay, in an area outside of the runoff influence. No in-channel sample was collected upstream of the bay. The second event occurred on February 12, 2000, and was larger with rainfall amounts of nearly 1.0 cm. The plume mapping during this event occurred exclusively during flood tide; tidal heights increased 0.7 m during the surface water measurements. Plume mapping activities required

4.72 hr to complete. Nine samples were collected for toxicity analysis. One sample was collected from the in-channel site upstream of the bay and eight samples were collected from receiving water sites that ranged from nearest the creek mouth to the open bay outside of the plume influence. The third event occurred on March 5, 2000, and was the largest event sampled. Rainfall quantities exceeded 1.6 cm and plume mapping occurred exclusively during ebb tide; tidal heights decreased 1.8 m during the surface water measurements. Plume mapping activities required 5.12 hr to complete. Nine samples were also collected for toxicity analysis during this event. One sample was collected from the in-channel site upstream of the bay and eight samples were collected from receiving water sites that ranged from nearest the creek mouth to the open bay outside of the plume influence.

Plume mapping

The extent of the stormwater plume varied by size of storm, but was large enough to extend across the bay beyond navigable waters (Figure 1). The area of decreased salinity, defined as ≤32 practical salinity units (psu), and increased turbidity, relative to open bay water, extended from less than 0.02 km^2 during the smallest storm event to 2.25 km^2 during the second runoff event. The most concentrated portions of the plume were always located nearest the creek mouth, within the channel leading to the bay, and decreased away from the creek mouth as mixing and dispersion with open bay water occurred. During larger events, sufficient runoff volumes were discharged so that plumes were advected more than 2 km away from the Chollas Creek mouth out into the open bay.

Freshwater runoff plumes floated over the denser bay water and formed lenses that were thickest near the creek mouth and thinnest near the margins (Figure 2). The depth of the plume nearest the creek mouth ranged from 2 to 4 m, depending upon the amount of rainfall (i.e., discharge volume) and overall water depth. The vertical water column structure showed that complete mixing occurred within the first 400 m of the creek mouth during the first and smallest event, and extended more than 1,500 m offshore during the second runoff event. The second storm event also penetrated deepest into the water column.

Turbidity (transmissivity in beam C units) measurements also clearly defined the margins of the plume (Figure 2). Transmissivity results were similar to the salinity measures for the cross-shore water column structure; the thickest plume penetration was nearest the creek mouth, and the freshwater lens thinned near the plume margin out in the open bay. Transmissivity at the margins changed up to 20% within a distance of meters. These changes were so dramatic they were visible to field crews aboard the research vessel during surveys.

Spatial Extent of Toxicity

Tests of San Diego Bay surface water samples collected during three runoff events revealed the presence of toxicity offshore of Chollas Creek.

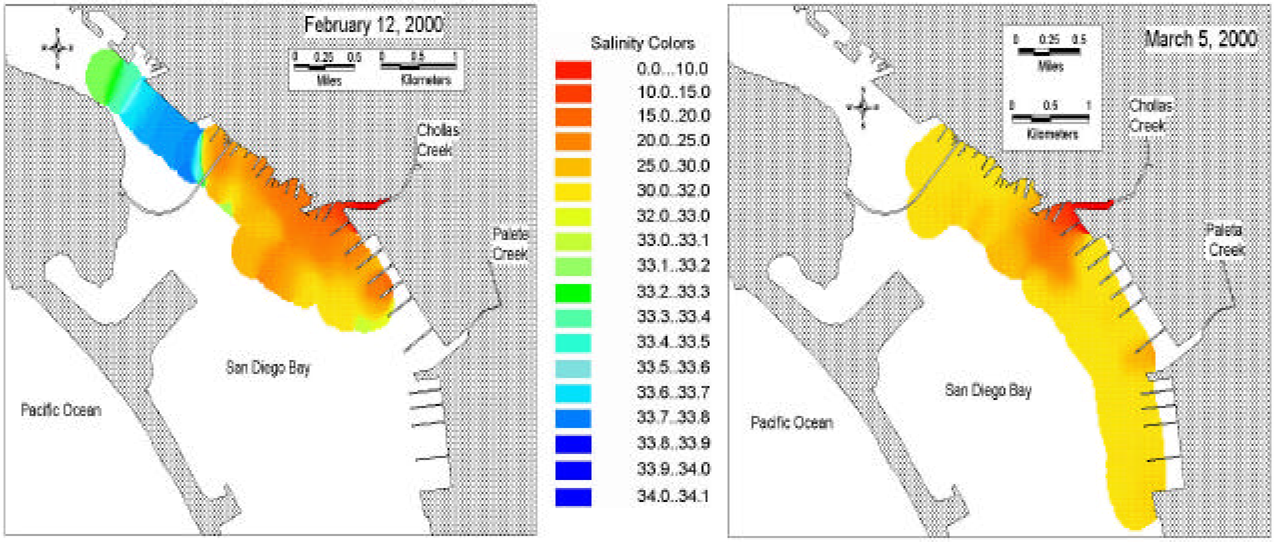

Figure 1. Surface plume mapping of salinity (in practical salinity units, psu) offshore Chollas Creek during two separate storm events (February 12 and March 5, 2000).

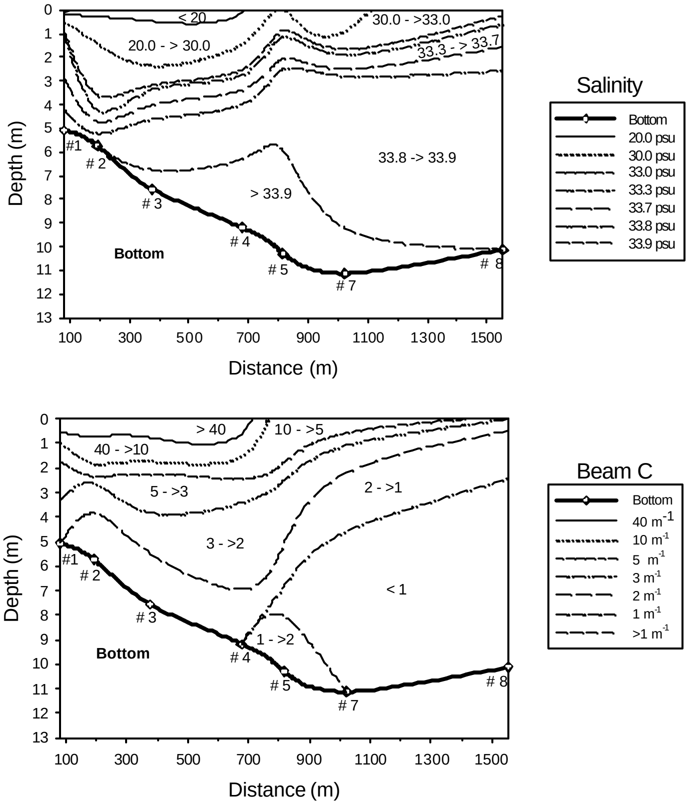

Figure 2. Salinity (practical salinity units, psu) and turbidity (Beam C attenuation in meters) in water column cross-section moving offshore from the Chollas Creek mouth into San Diego Bay following the second storm event (February 12, 2000).

Toxicity to sea urchin sperm was detected in all samples collected within the portion of the plume containing ≈10% runoff (as determined from salinity measurements). Fertilization (normalized to the control response) in these samples ranged from 5 to 74%. The highest magnitude of toxicity was found in samples taken near the mouth of Chollas Creek. Reference samples of San Diego Bay water collected from 0.3 to 1.5 km outside of the plume were non-toxic, with fertilization values of 88 to 100%. Changes in toxicity corresponded with changes in salinity across the plume gradient emanating from Chollas Creek.

The boundaries of the discharge plume and the toxicity plume differed (Figure 3). In the second runoff event, the toxic portion of the plume (the region producing <80% fertilization), extended across 1.03 km^2 of the bay and comprised approximately 50% of the physical extent of the plume. The size of the toxic portion of the plume measured during the third runoff event was smaller, covering an area of 0.24 km^2, as was the physical extent of the plume during the third event (0.98 km^2).

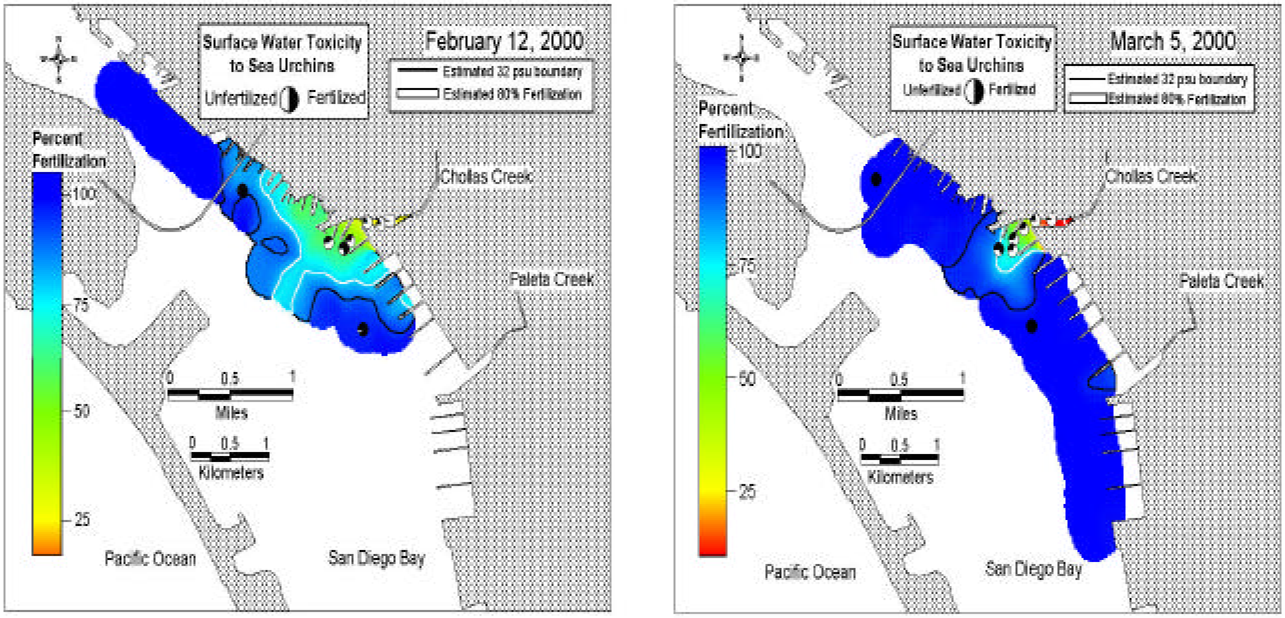

Figure 3. Map of surface layer water toxicity to sea urchins in San Diego Bay associated with Chollas Creek discharges following two separate storm events. The colors show the estimated percent of sea urchin fertilization based upon the toxicity results for water samples (indicated by pie diagrams) and measured salinity in the surface layer.

Magnitude of Plume Toxicity

Surface water samples collected near the mouth of Chollas Creek during the second and third storm events, both of which were dominated by runoff (salinity <1 g/kg), had a similar magnitude of toxicity (4.0 and 3.9 TUs, respectively). The EC50s for these samples were 25 and 26%, respectively. The NOECs for these samples were 3 and 12% for the second and third events, respectively. These data indicate that strong toxic effects are expected to occur in portions of the plume containing ≥25% runoff.

The overall magnitude of toxicity in the plume samples was similar to that measured from Chollas Creek in-channel samples during each runoff event. The channel composite was slightly more toxic (5.9 TUs) than the plume sample during the second event, while the creek composite sample for the third event contained 3.4 TUs, which was similar to the plume sample. The NOECs for the creek composites (3 and 12%) were the same as those measured for the plume samples, indicating that the threshold concentration for toxicity was similar in both types of samples.

Similarities in the magnitude of toxicity were also evaluated by comparing the dose-response curves of the creek composite sample to the toxicity of San Diego Bay surface water samples collected during each event (Figure 4). The toxicity of surface water samples were similar to that measured in the corresponding creek composite sample diluted to contain a similar concentration of runoff. This indicates that most of the plume toxicity could be accounted for by dilution of creek discharge.

Identification of Toxicants

Phase I TIE tests consistently demonstrated that EDTA effectively eliminated toxicity and STS was ineffective for both in-channel and both plume samples (Table 1). Particle removal by centrifugation was only partially effective in samples from one event. Treatment using a C-18 solid phase extraction column removed the toxicity in three of four samples, including both in-channel samples. Elimination of toxicity by EDTA is an indication that trace metals are likely constituents responsible for toxicity.

No toxicity was detected in solvent eluates of the C-18 columns that removed toxicity during the Phase I tests. The DCM or MeOH eluates of the columns tested at 2 to 3 times the original concentration in the aqueous sample were non-toxic to sea urchin sperm; fertilization in these samples was 93 to 100% of the

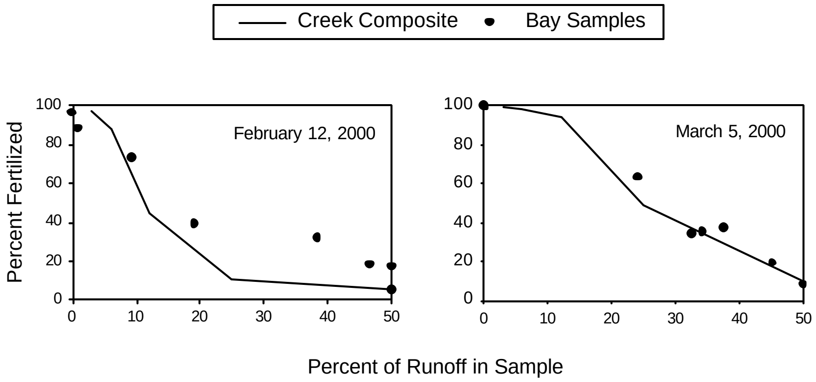

Figure 4. Comparison of sea urchin toxicity in San Diego Bay surface water samples to the dose-response curve obtained from in-channel samples obtained from Chollas Creek during storms two (February 12, 2000) and three (March 5, 2000).

Table 1. Summary of Phase I toxicity identification evaluation (TIE) results for stormwater samples taken from Chollas Creek and bay surface water samples taken from the runoff plume near the mouth of the creek. Each sample tested contained 50% runoff.

			TIE Treatment (% fertilization)			
Date	Sample Type	BaselineToxicity (% fertilization)	Centrifuge	C-18 Column	EDTA	STS
2/12/2000	Creek	6	8	98	100	6
2/12/2000	Plume	5	12	5	91	5
3/5/2000	Creek	10	41	95	85	15
3/5/2000	Plume	8	46	98	88	7

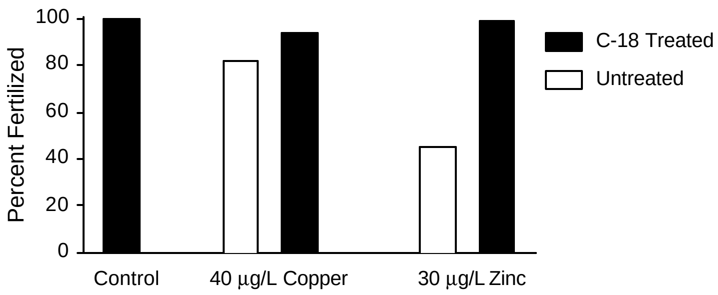

Figure 5. Effect of C-18 column treatment on the toxicity of metal-spiked seawater to sea urchins.

control value. These results indicate that the toxicants removed by the C-18 column either had polar characteristics or had degraded during storage prior to elution.

A Phase II experiment was conducted in order to investigate the effectiveness of the C-18 column treatment on dissolved trace metals. The toxicity of seawater solutions spiked with toxic concentrations of copper or zinc was eliminated after C-18 column treatment (Figure 5). The effect was particularly noteworthy for zinc, where a solution causing a 55% reduction in fertilization was rendered non-toxic after passage through the column. These tests used the same type of column and procedures that were used in the Phase I experiments.

Eight metals were identified as having elevated concentrations in the composite sample relative to those in surface water (Table 2). Aside from iron, dissolved zinc and copper were present in the highest concentrations in samples collected from within Chollas Creek. Zinc levels from the most concentrated portion of the plume (essentially 100% stormwater discharge) ranged from 92 to 152 µg/L; these concentrations were above the zinc EC50 determined from previous fertilization experiments (29 mg/L). Copper concentrations in the same samples ranged from 37 to 66 µg/L, which also exceeded the EC50 for copper (31 µg/L) measured in reference toxicant tests conducted during this study. Background concentrations of zinc and copper in the bay during this study were approximately 14 µg/L and 3 µg/L, respectively. Little is known about the sensitivity of sea urchin sperm to the other metals in Table 2.

Gradients in dissolved zinc concentration among the San Diego Bay surface water samples showed a dose-response relationship with sea urchin fertilization

Table 2. Salinity (practical salinity units), sea urchin toxicity (percent of control fertilization), and dissolved concentration of selected metals in Chollas Creek and San Diego Bay water samples. Plume samples were collected from the portion of the plume having the lowest salinity while the bay samples were collected outside of the plume. Median effects concentration (EC50) and no effects concentration (NOEC) values for selected metals were calculated from independent fertilization experiments.

	Sample	Salinity	Fertilized	Metal Concentration (µg/L)							
Date	Type	(psu)	(%)	Sb	Cr	Cu	Fe	Mo	Ni	V	Zn
	EC50					31					29
	NOEC					20-44					5-10
1/25/00	Plume	32.9	74	0.19	0.12	2.46	6	8.92	1.24	2.03	16.50
1/25/00	Bay	33.8	94	0.14	0.16	3.21	2	8.61	0.91	2.04	11.40
2/12/00	Creek	0	6	17.56	2.68	51.20	2,184	25.80	10.72	11.14	150.80
2/12/00	Plume[a]	0	18	3.45	1.93	36.88	1,752	14.6	8.75	12.57	92.00
2/12/00	Bay[a]	32.4	92	0.18	0.15	3.08	1	8.95	0.94	2.06	13.80
3/5/00	Creek	0	10	8.32	3.36	63.00	3,080	25.20	12.44	11.28	146.00
3/5/00	Plume	0	8	6.20	3.30	65.60	3,260	26.40	13.78	13.44	152.20
3/5/00	Bay[a]	32.6	100	0.16	0.14	3.22	3	9.44	10.42	2.00	14.30

[a] Mean of two samples for this entry, all other values represent single samples.

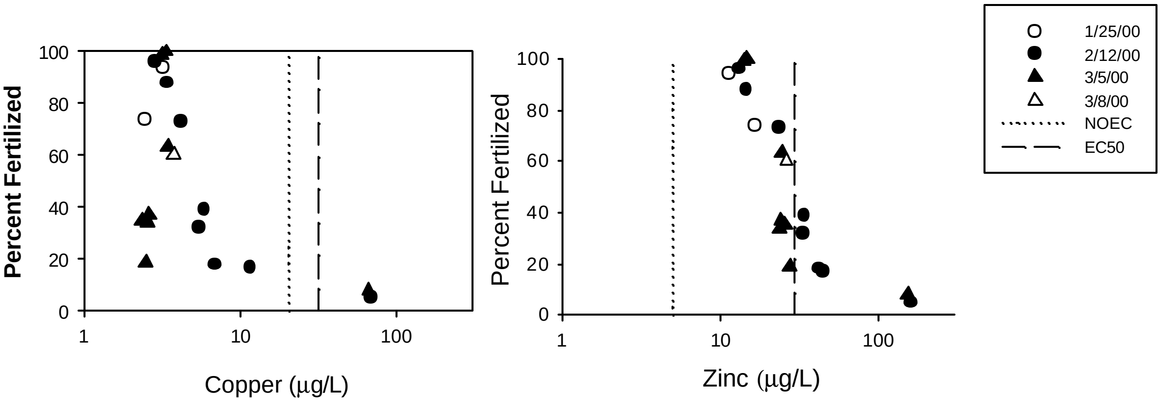

Figure 6. Comparison of sea urchin toxicity to dissolved zinc concentrations in San Diego Bay surface water samples collected during three storm events. Reference lines indicate the no effect concentration (NOEC) and median effect concentration (EC50), which was determined from laboratory experiments by Bay *et al*. (1997).

(Figure 6). Fertilization percentage declined as zinc concentration increased, and the magnitude of effect was consistent with the dose-response relationship for zinc determined from prior laboratory experiments with spiked seawater. For example, large reductions in fertilization were observed in samples containing dissolved zinc concentrations similar to or greater than the EC50 value. A similar plot for dissolved copper also indicated a correspondence between toxicity and concentration, but the data were more variable and did not correspond as well with the NOEC and EC50 for copper-spiked seawater (data not shown). Many of the toxic samples contained less copper than the NOEC, indicating that the toxicity was not caused by copper. The two samples containing copper concentrations above the EC50 were highly toxic, however.

Toxic unit calculations based upon zinc and copper EC50s confirmed that these two metals were present in sufficient concentrations to cause most of the toxicity measured in the heart of the runoff plume and in the in-channel samples. Most of the toxicity measured in each sample was attributable to zinc, and the total amount of toxicity calculated from zinc plus copper accounted for 72 to 109% of the total toxicity measured in the samples.

DISCUSSION

The wet-weather events sampled from Chollas Creek generated large volumes of stormwater runoff that extended across more than 2 km^2 of San Diego Bay. These plumes were turbid and, because the freshwater discharge was less dense than seawater, they formed lenses of 2 to 5 m thickness on the surface of the bay. Thin stormwater plumes of large areal extent have been observed offshore other urban watersheds in southern California. Plumes extending over 4 km^2 and 3 m thickness were measured offshore Ballona Creek following storm events of 7 cm and greater (Bay *et al.* 1999). Similarly, thin plumes were measured in upper Newport Bay following storm events discharging runoff from urban areas of the San Diego Creek watershed (Lee *et al.* 1999).

Several limitations apply to the plume measurements made as part of this study. The first limitation is attempting to describe a fixed plume extent when plumes are dynamic water quality features. For example, our plume surveys lasted up to 6 h, yet plumes can shift and change in size or shape over the course of a tidal cycle. A second limitation to our plume mapping abilities was the difficulty of attempting to extrapolate our measurements to unmeasured areas. We used a kriging method to construct our plume maps. However, kriging techniques work best under steady state conditions, an assumption that was violated at times during our surveys because plumes, particularly during flooding events, are dynamic. On the other hand, we were able to find the plume margins using distinct salinity and turbidity signatures. Hence, our estimates of plume extent were verified using empirical data. Moreover, the repetitiveness of the plume extent over multiple storm events adds confidence to our assessment. In fact, the storms we measured were not extraordinarily large and a greater extent of impact may occur during larger sized events.

Plume toxicity was directly related to toxicity measured in the Chollas Creek discharge. The magnitude of toxicity near the creek mouth was similar to the toxicity measured from within the creek. The magnitude of toxicity then decreased as the plume mixed away from the creek mouth until, reaching outside the plume margin, the toxicity was not observed. In fact, the toxicity could be predicted as a function of salinity. Further, the magnitude of toxicity in the creek discharge was similar to that of the discharge plume after accounting for dilution of the plume with bay waters. These findings are consistent with plume toxicity measurements taken offshore of other creek mouths in southern California (Bay *et al.* 1997). Offshore of Ballona Creek, toxicity was observed using the purple sea urchin test, and it was in direct proportion to the amount of stormwater present in that plume.

Not only was the plume toxicity proportional to the amount of freshwater mixing, but the same constituents were identified as the toxic agents from the creek and from the plume. Zinc was implicated as the primary toxicant to the purple sea urchin in Chollas Creek discharges during the 1997/1998 wet season (Schiff *et al.* 2001) and again during this study. Zinc was also implicated as the primary toxicant to the purple sea urchin in the stormwater plumes in San Diego Bay that emanated from Chollas Creek during this study. However, this finding was different from TIE testing with other species, such as the freshwater daphnid *Ceriodaphnia*, which was sensitive to other constituents (e.g., organophosphate pesticides). We do not expect all species to be affected similarly to stormwater exposures. While we observed some very compelling evidence that Chollas Creek stormwater affected purple sea urchins, this finding may not be applicable to other marine species. We continue to conduct research on the linkages between single species toxicity tests and ecological consequences at the population and community levels.

Stormwater plumes are not the only source of pollutants that generate water column toxicity in San Diego Bay. The toxicity observed in the wet-weather plume offshore Chollas Creek was greater than the toxicity observed in other 303(d) listed portions of San Diego Bay (RWQCB unpublished data). For example, purple sea urchins exposed to receiving waters sampled from the Shelter Island Yacht Harbor in San Diego Bay yielded NOECs of 20% whereas samples taken from the Chollas Creek wet-weather plume yielded NOEC values as low as 3%. Similarly, dissolved zinc and copper concentrations were as much as an order of magnitude higher in the wet-weather plume than in the yacht harbor. However, the toxicity in the Shelter Island waters persists every day of the year while the toxicity in the plume persists for at least 3 d following runoff events. When prioritizing areas for remediation, managers need to decide whether increased toxicity for shorter time periods is more important than persistent low-level toxicity.

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ACKNOWLEDGEMENTS

This project was partially funded through the State Water Resources Control Board. The authors are grateful for the review provided by the City of San Diego, Port of San Diego, US Navy SPAWAR, and San Diego BayKeeper. In-channel sampling was conducted by URS-Woodward Clyde America. Field sampling was accomplished using the R/V *Fisherette*. Many thanks to David Tsukada, who assisted in field sampling.